About Charge Density Wave for Electromagnetic Field-Drive

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Abstract

To generate a propulsive force without propellant and external couplings, it has been shown that two confined macroscopic and time-varying charge density waves well separated in space are needed. Here, some physical conditions will be proposed to support and maintain these particular collective modes of charge distributions.

I. INTRODUCTION

Within the framework of classical electrodynamics, it has been shown [1] how an electromagnetic propulsive force and, in particular, an electric (conservative) propulsive force can be generated without propellent mass and external couplings by using two confined, time-varying, neutral and macroscopic charge density waves (CDW). These CDW own a same symmetry axis, are adequately separated in space and have a relative temporal phase-shift. This last one controls the propulsive force's intensity.

From far fields point of view, these CDW are able to induce an asymmetry into the space distribution of the far fields momentum variation rate along the symmetry axis. They can do that because the relative temporal phase-shift controls the space distribution of constructive and destructive interferences of far fields produced by the two CDW [1]. So, this relative temporal phase-shift controls the asymmetry. When this last one is created, an electromagnetic propulsive force along the symmetry axis is generated and applied on both CDW in a same direction. Such propulsive effect is impossible in statics because fields' interferences can be produced only with time-varying fields. Because this propulsive force is generated by a spatial asymmetry in the (electromagnetic) field, it is a propulsion driven by the electromagnetic field or more simply an electromagnetic field-drive (EFD).

In our first paper [1] we have used the CDW concept in a theoretical way. Actually, nothing has been said about the material or the conductive fluid needed to sustain a neutral macroscopic charge density wave. The only thing we have mentioned was this CDW is a longitudinal (i.e. ϕ direction in cylindrical coordinates) charge oscillation mode, it has a wave number "n", it oscillates at frequency ω and it is pinned (circular standing wave) inside a ring made with an electrical conductor. In this simplified model, we have used two identical planar filiform rings with radii R', placed in vacuum and separated by a distance D along the z axis. Planes of rings were perpendicular to the z axis; the symmetry axis, the thrust axis. In a more realistic way, rings have a cross section R_o smaller than D and R' according to section 4 in [1]. However, we have never mentioned that a relation must exist (dispersion relation) between n and ω and what is this relation. Furthermore, what are needed conditions to support and maintain a time-varying CDW able to create the desired propulsive effect? Is it possible to use solid rings? Metallic ones? Or what else? In this work, we would like to give preliminary and partial answers to some of those questions.

II. A LONGITUDINAL PLASMA MODE

A time-varying longitudinal CDW involves a time-varying longitudinal charge separation among opposite charges. In that case, there must be a restoring force among these charges and consequently, this creates a collective oscillation mode (i.e. longitudinal plasma mode) at plasma frequency ω_p [2,3,4,5,6]. So, to sustain a large amplitude of charge separations in a neutral conductor or, more generally, in a conductive "fluid" and then support and maintain sources of large electric fields, our frequency ω must be close to (at least equal or greater than) the "resonant" frequency ω_p. Thus, we will get an appropriate CDW (n≠0) if each neutral conductive fluid of our two rings is a neutral plasma.

The other reason to use a $\omega > \omega_p$ is this. In a sense ω_p can be considered as a cut-off [7]. So, if ω is greater than this cut-off, fields created by one conductive fluid in a given ring will penetrate deeply inside the conductive fluid of the other ring to create propulsive effect throughout the ring's cross section for non-filiform rings (i.e. torus for instance). Actually, if $\omega < \omega_p$ fields generated by one ring will remain near the surface of the other; they will be mostly reflected by this one and they will be nearly zero inside of it except to its surface. In such a case, the thrust's amplitude will be limited and restricted to the rings' surface. In addition, this will increase the probability of cold emission like in a metal (see below) because fields must be relatively strong (i.e. at least about 100kv) to get a good thrust [1]. So, things like that can reduce the propulsive effect.

According to the model in [1], the value of ω must be in the range of radio frequency or TV range. Consequently, our plasma must have a ω_p in these ranges too. However, if n=0 there are no charge separations at all; we have only a uniform longitudinal current on each ring. In this last case, we don't need a longitudinal plasma mode; a

neutral conductive fluid with a ω_p much larger than ω can be used. But let's remember this, if n=0 the propulsive force has no electric contribution (i.e. no conservative part), only a magnetic one (i.e. a dissipative part because radiative) and we know that this last contribution has a poor efficiency according to section 6 in [1].

For our purpose and for now, at least four limits or conditions must be considered in a neutral plasma. The first is related to the collision rate f. Our macroscopic time-varying CDW is a collective oscillation mode; a longitudinal plasma mode. Collisions break "coherence" among charges' motions and then break the collective oscillation and, the CDW itself can be destroyed. To get collective oscillations, we must have $f \ll \omega_p \sim (e^2 n_o / m_e \epsilon_o)^{1/2}$ (SI units) [2,3,4,5,6]; m_e is the effective electron's mass, e the electron's charge, n_o the electron density when n=0 (for electronic plasma with heavy positive ions as uniform background) and ϵ_o is the vacuum electrical permittivity. We have to mention that f increases with n_o and temperature (see below).

The second limit is associated with the wave number or the wave length of the charge density in a conductive fluid. For us, this is related to "n". There is an upper limit for this wave number. Above this limit, the CDW cannot oscillate; the damping (i.e. Landau damping [8]) is too strong and thus, CDW does not exist (it's too "viscous"). In a nondegenerate conductive fluid, like an ionized gas with relatively small density of electrons and ions for instance, this upper wave number is the Debye wave number k_D given by ${k_D}^{-1} \sim (T_e/n_o)^{1/2}$ cm [9,10] (n_o in cm^{-3}). T_e is the electrons' temperature (in Kelvin); a measure of their mean kinetic energy. An electron within ${k_D}^{-1}$ cannot move easily ("viscous" area) but outside, it can. So, if the wave length of our CDW is larger than ${k_D}^{-1}$, the damping won't exist or it will be weak or quite weak and then, this CDW will survive and will be able to oscillate.

In a degenerate neutral conductive fluid like an electron gas in a solid metal at low temperature (i.e. low compared to the Fermi energy E_F [11,12]), k_D is replaced by the Fermi wave number k_F [9]. In that case, the typical kinetic energy is E_F not T_e.

In our situation, we need a neutral plasma with $\omega_p \sim$ 100 MHz (radio frequency as order of magnitude) and a ${k_{DorF}}^{-1}$ smaller than about 10^{-2} cm. 10^{-2} cm is a lower limit for the wave length of our CDW; a macroscopic length scale for which our classical approach in [1] is certainly correct. With solid alkali metals like Li, Na, etc. or solid noble metals like Cu, Ag, Au, ${k_F}^{-1}$ respects the above condition. For example, solid copper (Cu) at room temperature ($\sim$ 300K), ${k_F}^{-1} \sim 10^{-8}$ cm [13,14]. But the problem with solid metals like alkali (or noble) is their ω_p belong to ultraviolet frequency range ($\sim 10^{15}$Hz) [15,16]. The reason for such a big value is a large n_o ($\sim 10^{22}$ cm^{-3}) [16] and a very small effective mass of charge carrier (i.e. electron). So, solid metals can bee used only if n = 0 (i.e. uniform currents on rings) according to above discussion ($\omega < \omega_p$).

For instance, if n = 0, we could use two metallic and solid torus (i.e. planar rings with cross section R_o smaller than D and R' according to above), fixed apart with distance D by some adequat isolators and placed in good vacuum at "room temperature". However, one possible problem with metals is the cold emission [17]; when fields applied over metallic crystal become relatively strong, electrons (carriers) can be expelled outside the crystal by "quantum tunneling". In that case, the charge's momentum of carriers won't be given to the whole crystal along the thrust axis so, the momentum transfer efficiency will be diminished and then, the propulsion too. Furthermore, with metals we will have $\omega < \omega_p$ and, as mentioned above, this is limitative.

With n $\neq$ 0, we need something else. For instance an ionized gas; a neutral conductive gas formed by electrons and ions with a smaller electron density: $n_o \sim 10^8$ cm^{-3}. In that case this neutral plasma has a ω_p in the range that we want according to its expression given above. On the other hand, we want a relatively "cold" plasma because we wish to satisfy the condition $f \ll \omega_p$ and also because we want to avoid any complications about plasma confinement ("walls"). For example, let's consider a temperature T_e between 1000K to 10000K. Such values for T_e and n_o give us a ${k_D}^{-1} \sim 10^{-3}$ to 10^{-2} cm according to the above expression so, they give us a classical plasma (i.e. nondegenerate electrons gas where classical statistics can be applied) quite similar to the ionosphere's one [18]. Actually, at 90km into ionosphere, collision rate is $f \sim 10^6$Hz and at 300km, $f \sim 10^3$Hz [19]. Such last values respect the preceding inequality between f and ω_p. This doesn't mean ion species we need must be the same as the ionosphere's ones. Best ion species we need is another issue. But it shows that such a kind of plasma exist. So, a priori, a neutral ionized gas with relatively "low"temperature, 10^3 to 10^4K, and low electrons density, $n_o \sim 10^8$ cm^{-3}, (i.e. a cold plasma) could be a good candidate for our purpose when n $\neq$ 0.

Let's take an example to get an order of magnitude of the propulsive force when a cold plasma gas is under consideration. Let us consider a lithium gas with electrons density $n_o \sim 10^8$ cm^{-3} and electrons temperature $T_e \sim$ 5000K. According to above expressions, ω_p $\sim$ 564MHz and ${k_D}^{-1} \sim 7\times10^{-3}$ cm. By simplicity, let's imagine all atoms of lithium are ionized such as Li $\rightarrow$ Li^+ + e^-. Atomic weight of Li is about 6.9a.m.u. so lithium mass density is about: $n_o \times 6.9 \times 1.66 \times 10^{-27}$kg $\sim$ 10^{-18}kg/cm^3. (Of course, this doesn't take into account the mass of confining "walls"). Mass of Li^+ is about 10^4 times larger than the one of e^-. So, ion Li^+ is at rest compared to e^-; only electrons move at frequency ω along ϕ direction. Now to get an order of magnitude of the propulsive force, we can use the Coulomb force expression. Coulomb force is one of main contributions (conservative part) to the thrust in [1]. So, in these conditions if we consider a small volume of 1cm^3 of charges on each ring (or torus), the force we can get between

these small volumes if D = 0.1m (same order of magnitude than the one used in [1]) is given approximately by $(1\text{cm}^3)^2 \cdot \left({n_o}^2 e^2/4\pi\epsilon_o D^2 \right) \sim 10^{-10}$N. This evaluation is a *maximum* one because it doesn't take into account destructive interferences among fields produced by positive and negative charges in a same CDW and applied over charges in the other CDW.

The reason for such a small force is the relatively small value of n_o. If we increase n_o, condition ${k_D}^{-1} \ll 10^{-2}$ cm will be always satisfied but certainly not $\omega_p \sim 100$MHz. However, if we use an "ionic plasma" instead of an "electronic one" as in the above example, we will have $\omega_p \sim (q^2 n_o/m_i\epsilon_o)^{1/2}$ and ${k_D}^{-1} \sim (T_i/n_o)^{1/2}$ cm where n_o is now the ions density, T_i the ions temperature, m_i is the reduced mass of ions and q, their charge. Consequently, if n_o is increased, we will keep ω_p fixed if we take an appropriate reduced mass m_i larger than m_e. Let's give an example.

Let's take Li + Cl $\rightarrow$ Li^+ + Cl^-. Ion chlorine Cl^- is about 5 times heavier than ion Li^+ so, $m_i \sim m_{Li} = 11.4\times10^{-27}$kg, $q = e$ and $T_i \sim T_{Li}$. As before we take same temperature $T_{Li} \sim 5000$K. Now to get the same plasma frequency; $\omega_p \sim 564$MHz, we must take $n_o \sim 1.3\times10^{12}\text{cm}^{-3}$. In that case, ${k_D}^{-1} \sim 6.2\times10^{-5}$cm and $(1\text{cm}^3)^2 \cdot \left({n_o}^2 e^2/4\pi\epsilon_o D^2\right) \sim 3.9\times10^{-2}$N with the same D as before. However, condition $f \ll \omega_p$ is not respected. We can evaluate f by using its expression [20,21] for an ideal gas (i.e. low density and pressure). One has $f \sim n_o \bar{v} \sigma_{Cl} = n_o (8k_B T_{Li}/\pi m_{Li})^{1/2} \sigma_{Cl} \sim 6.2$GHz. k_B is the Boltzmann's constant, $\sigma_{Cl} \sim \pi({k_D}^{-1})^2$ is the scattering cross section of the screened chlorine ion and $\bar{v}$ is the mean speed of lithium ion; this velocity is close to the relative velocity between lithium and chlorine ions. Finally, mass density is $n_o(6.9+35.4)\times1.66\times 10^{-27}\text{kg} \sim 9.1\times10^{-14}\text{kg/cm}^3$. So, as we can see, the choice of ion species is quite important.

The neutral plasma gas must be ionized by some external source (at the beginning at least) but, because temperature is relatively small, after a specific time there are recombinations among electrons and ions (or ions-ions) and then a radiation (named secondary here) is emitted. The primary radiation is the one emitted by the longitudinal plasma oscillations of both CDW at frequency $\omega \gtrsim \omega_p$. Other kinds of secondary radiations can also be emitted like breaking radiation (bremsstrahlung) [22,23] and spectral radiation coming from excited atoms (not ionized). Recombinations among charges imply that a third limit has to be considered in our neutral plasma. This limit is given by $f_r \ll \omega_p$ where f_r is the recombination rate between negative and positive charges. Clearly, this quantity depends on electrons (or ions) density n_o and electrons (or ions) temperature T_e (or T_i). f_r increases when temperature decreases because kinetic energy of opposite charges (i.e. their thermal energy) becomes smaller than their potential energy (i.e. mutual attraction). This is why temperature, on the other hand, cannot be too small.

III. ANISOTROPIC CONDUCTIVE GAS

According to the model given in [1], charges must be well confined along the z direction (i.e. the thrust direction) and along the ρ direction in some restricted regions (i.e. "filiform" rings). So, some constraints have to exist to maintain charges in these limited areas along those directions. These constraints have to ensure also the momentum transfer from charges to confining "walls", specially along z. In that sense, the conductive fluid (or gas) must be strongly anisotropic; charges can move easily along ϕ but should be nearly "at rest" along z and ρ directions.

Now, to get an appropriate anisotropic conductive gas (ionic and cold plasma gas), the cross section's radii R_o of a ring (or torus) must be smaller or equal to ${k_D}^{-1}$ so, the fourth limit is $R_o \lesssim {k_D}^{-1} \sim 6.2 \times 10^{-5}$ cm (using preceding value of chlorine-lithium gas) so, a "micro-torus" with a relatively large radii R'. The reason is this. Any charges inside ${k_D}^{-1}$, around the heavier ion; the Cl^- in our previous example, are in "viscous" area. This is true for Li^+ ions and for induced dipoles of the dielectric "walls" (see below). Consequently, with the above limit, any relative motions between Cl^- and Li^+ along z and ρ are quite well limited and this is true also among Cl^- and dipoles, induced by this ion, inside the internal surface of the dielectric walls along those directions.

In addition, the wall of this micro-torus must be a good dielectric. The neutral ionized gas will fill the micro-torus. The dielectric wall must be transparent to primary and secondary radiations. This is obvious for primary fields according to above; fields must reach the gas. But it is also important for the secondary to maintain a fixed temperature and get and sustain an equilibrium between ionization and recombination. Furthermore, this dielectric wall must be able to support high mechanical stress and relatively high temperature.

IV. CONCLUSION

In this paper, a well confined neutral ionized gas at relatively low density and temperature (i.e. a nondegenerated conductive gas; a "cold plasma") is proposed as a substrate in which a CDW ($n \neq 0$) can be sustained; the CDW needed to produce a conservative propulsive force, according to the model given in our first work.

Up to now, cold plasma is probably the most appropriate material able to create conservative propulsive force and meet conditions given in this paper. But, plasma stability, plasma confinement, momentum transfer from accelerated charges to the confining "walls" along the thrust axis, choice of best ion species and dispersion relation are certainly complicated issues to deal with in the near-term. In addition, the fourth condition is difficult to satisfy from a technological point of view now. On the other hand, as shown in [1], this model (i.e. rings

and the specific charge and current density distributions used; the CDW) has a poor efficiency. For all of these reasons, modifications to this model (i.e. to charge distributions) are needed to get a more efficient and realistic near-term EFD.

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